Sedimentation Within the Woolston Cut And Its' Associated Flood Risks

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Abstract

This research aims to examine the recent infill of sediment within the Woolston Cut and to determine the environmental and human impacts caused by this sedimentation. The Woolston Cut is a man-made canal located in the Heathcote River that was developed as a flood mitigation measure which has been very reliable in lessening floods caused by the Heathcote River; however, the several recent high magnitude earthquakes that hit Christchurch from 2010-2011 have caused damage to infrastructure and a massive accumulation of sediment within the Woolston Cut. There are several potential sources from which this sediment may have stemmed. Possible effects of this sedimentation include an increased risk of flooding and contamination of the land due to raw sewage in the water. Original architectural plans showing the design of the Woolston Cut were used for this research to determine the original storage capacity and dimensions. Surveys conducted by the Christchurch City Council were obtained and used to determine the amount of sediment that has accumulated within the cut. Google images and personal photo analysis, accompanied by infield measurements and surveying were done to determine the extent of damage that occurred in the Woolston Cut and to examine the increase of sediment in the Cut post-earthquake. Based on the CCC data and field surveying, a sediment rate and sediment volume was determined. Publications showing past flood events and the occurrence of liquefaction and lateral spreading were also researched. The ultimate goal of this research is to ensure the safety of the people and adjacent land and to provide mitigation measures to prevent flood risk.

Introduction

New Zealand is a country susceptible to several natural hazards considering its location on the Alpine Fault in the South Island and the active Taupo Volcanic Zone on the North Island. However, perhaps its number one natural hazard is that of flooding. Floods are the most frequent and costly natural disasters in New Zealand – between 1920 and 1983, the country experienced 935 damaging floods (an average of 15 per year) (McSaveney, 2009). The most recent estimate in 2004 of flood damage costs and civil defence *responses* averaged around $32 million per year.

An area that is rather susceptible to flooding is the city of Christchurch which may be the largest New Zealand city to be built on a flood plain. My research will focus specifically on the lesser known river of Christchurch which is the Heathcote River.

The Heathcote River drains a catchment of approximately 100 km^2 in the area above the Ferrymead Bridge, flowing into the Avon-Heathcote Estuary (Christchurch City Council, 1998). It has a gentle gradient, and at times of high tides and heavy rainfall there is a backing up of water which can cause extensive flooding in the Beckenham and Opawa suburbs (Roper-Lindsay, 1994). In 1986, due to this flooding, the Woolston Cut, a canal which causes flood waters to bypass a long loop of the river and rapidly flow through the cut, was opened (Roper-Lindsay, 1994).

However due to the development of the Cut, salt-water intrusion started to destroy trees upstream and weakened the banks which caused them to start collapsing. After a few years, the bank collapses started to threaten nearby neighborhoods and roads, so the Woolston Tidal Barrage was built at the upstream end of the Woolston Cut and it is a control measure that opens the canal in times of floods (Roper-Lindsay, 1994).

Significance

This structure has been very reliable in lessening floods caused by the Heathcote River; however, the recent high magnitude earthquakes that hit Christchurch in September of 2010 and February of 2011 have caused damage to infrastructure and a massive accumulation of sediment within the Woolston Cut.

High levels of sediment in the Heathcote River are, in the main, caused by storm water from the steep and easily eroded loess soils of the Port Hills, as well as a lack of suitable vegetation to protect banks (Christchurch City Council, 2009). Significant flooding is associated with rather low intensity, long duration (48-72) rainfall events on these easily erodible soils (Oliver and Peters, 1993).

However, it has been noted that several effects such as increased fluvial sediment transport and aggradation and rapid coastal dune building occur post earthquake. When earthquakes occur sediment in certain areas, generally mountains, are vigorously loosened and since New Zealand has a high and regular rainfall, rain and rivers transport sediment downstream at a highly rapid pace (McFadgen, B. G. and Goff, J. R., 2005.). The aggradation of sediment causes a rise in elevation of the streambed; research has shown that the Avon/ Heathcote estuary and Heathcote River have risen by about 0.3m-0.5m (Environment Canterbury Regional Council, 2011).

Most of Christchurch city was mainly

swamp behind sand dunes, estuaries, and lagoons that have now been drained (Brown et al. 1995). Thus, much of the over bank deposits are made of sand and silt, which are generally in a loose state and susceptible to liquefaction (Orense et al., 2011). Not much liquefaction or lateral spreading occurred near the Heathcote River area after the September earthquake; however, after the February earthquake liquefaction induced ground damage was much more extensive and severe mainly due to the much higher shaking intensities (Giovinazzi et al., 2011). Many structures including houses, bridges, and the Woolston Cut were affected by liquefaction and lateral spreading. Liquefaction caused subsidence in and around these structures, and lateral spreading was the primary mechanism for bridge damage and damage to the Woolston Cut.

However, the easily erodible loess soils, lack of vegetation, and liquefaction are not the only contributors to sediment deposition in the Woolston Cut. After the February earthquake, sewage pipes in areas surrounding the Heathcote River were damaged so temporary lines were placed in the Woolston Cut. This caused raw sewage to accumulate in the Cut which is easily visible. The wastewater is a significant contributor of the nutrients ammonia, nitrogen, and dissolved reactive phosphorus to estuary water (ECAN, 2011).

After the earthquakes, discontinuities developed in confined aquifers and permeability increased in consolidated rocks causes numerous springs to emerge throughout the city and along the loess/ alluvium contact at the base of the Port Hills (Rutter, 2012). Since the Heathcote Rive is spring fed, the increased groundwater table also contributes to the flood risk.

Since the river does overflow at times, the higher water table and recent sedimentation is cause for concern. Increased amounts of water and the higher sediment content will cause an easier overflow of the banks and the occurrence of liquefaction caused localized subsidence, thus lowering the elevation and stability of houses. This will leave areas near the river much more susceptible to flooding.

Considering that the Woolston Cut is a flood mitigation measure, the aggradation of sediment within the cut is rather dangerous. If a rather large flood event were to occur, then the cut would not be able to handle the amount and velocity of water which would cause the water to seep over the banks and flood nearby houses.

Methods

Image analysis has been crucial in examining the change of sediment throughout time, especially pre and post-earthquake. Google images were used for aerial views and historical imagery.

Damage within the research site was surveyed to determine how lateral spreading affected the Woolston Cut and adjacent area; photos were also captured to record the damage. Figures 4 and 5 show areas where measurements were taken and the damage digitally captured.

Architectural schematics for the Woolston Cut were acquired from the Christchurch City Council to determine the original design and storage capacity of the cut.

Corel Draw was used to visualize the survey data acquired from the CCC. The graph of survey data was overlain onto the original schematic of the Woolston Cut. Sediment volume calculations for several cross sections across the cut were determined by this.

Test pits were dug near the concrete steps so that the depth of sediment could be easily determined. Photos showing the depth of the test pit were taken and a stratigraphic log of the sediment layers was constructed. Sediment rate calculations since the construction of the cut were determined through the stratigraphic log.

Publications containing information in regard to flood risks and the recent earthquakes were researched and documented to better determine how sediment may have accumulated in the cut over time. Also, the history of floods and liquefaction events within the Heathcote area were researched.

Results

Through image analysis and literature reviews, it was noted that sediment has accumulated within the cut from 2010 to 2011. The northern part of the Avon/ Heathcote estuary has subsided by 0.2-0.5m and the southern part of the estuary including the Heathcote River has risen by 0.3 to 0.5m (ECAN, 2011). This has caused a geological depression to form in the area.

We surveyed the damage around the Woolston Cut and noted that lateral spreading had offset the concrete wall of the canal and bank by an average of 9.4 cm and the canal itself had uplifted in some parts by an average of 6 cm. There was more uplift and apparent lateral spreading on the western side of the canal facing NW.

After overlaying the CCC survey data onto the original design of the Woolston Cut in Corel Draw, an interesting observation was made. The canal itself on the right side had moved inwards about 1 meter and upward 0.3-0.5m. The left side of the canal moved inwards approximately 0.3m and upwards 0.3-0.5m as well (See Figure 1).

Through the use of the data received from the CCC, sediment volumes were calculated for each cross sectional area. The lower reaches of the Woolston Cut have less sediment accumulation than that of the upper regions. The 2011 cross sectional volumes of sediment can be seen in Figure 2.

The original storage capacity of the Woolston Cut was ~62,394.56 m^3. However, the total volume of sediment throughout the cut in 2011 was approximately 29,212.5 m^3. This number is striking in comparison to the estimated sediment volume from 1990 which was ~ 10,074.0 m^3. So, in 21 years there has been an increase of 19,138.6 cubic meters of sediment within the Woolston Cut. This also means that nearly 47% of the cut has been infilled with sediment.

Through these estimated volumes, a sedimentation rate was determined:

1986-1990: 2,518.5 m^3/yr
1990-2011: 911.4 m^3/yr
1986-2011(Total): 1,168.5 m^3/yr

It is interesting to note the dramatic decrease in the sedimentation rate from 1986-1990 and 1990-2011.

The original designs were viewed and it was determined that there were 10 steps that led to the base of the structure which assisted in analyzing the depth of sediment within the cut across several channel sections. It was determined that exactly 4 steps and the base of the cut were covered by sediment. In the test pit that was dug, there was a vertical accumulation of about 80 cm of sediment. Nearly half of the canal was vertically filled with sediment as the length from the base to the bottom part of the precast unit (Fig. 3) measured 175 cm (this correlates with the filled capacity percentage which was 47%).

Using the sediment from the test pit a

stratigraphic log of the sediment from the test pit was created (See Figure 3).

Discussion

The geological depression that has formed in the Christchurch area due to subsidence in the northern regions of the Avon/ Heathcote Estuary and uplift in the southern region is important to note because not only does this mean that the Heathcote River is more susceptible to flooding due to the raised bed load, but also water will be concentrated in the depression during flood events causing concern for areas nearby.

The Woolston Cut itself has actually moved upwards and inwards due to lateral spreading caused by the earthquakes. This is evident not only through the infield survey we did but by the CCC data that was overlain on the original design schematic. This is interesting because the movement of the cut means that it has an increased elevation and lessened storage capacity. This factor accompanied with liquefaction and subsidence of the surrounding area means that there is a much higher potential for flood risk.

The sedimentation rate was extremely high from 1986-1990. This may be due to the fact that the cut had just been built and did not have the tidal gates causing much of the water and sediment to travel and accumulate in the canal. The dramatic decrease of the sedimentation rate from 1990-2011 may have been due to the construction of the Tidal Barrage.

The stratigraphic log of the sediment that was created from the test pit may show the events that occurred within the cut. The first layer, A (0-30 cm), shows the background sedimentation of a slightly coarse but well sorted sand, perhaps from 1986-1994. B (30-40 cm) is a more fine grained, well sorted silt which may have been deposited during the flood event in 1994. C (40-73 cm) is representative of the background sedimentation again as it is also sand sized and full of organic material. D (73-80 cm) which is fine black silt with yellow-brown excrement may have been deposited from liquefaction events that occurred within and near the river. The yellow-brown excrement was deposited by the temporary sewage lines that were placed within the cut after the earthquakes occurred.

Over 25 years, approximately 46.98% of the storage capacity of the Woolston Cut has been infilled with sediment. This means that on average 1.81% of the capacity is filled every year. This is an alarmingly fast rate for sedimentation within the canal. If the cut continues to fill with sediment at this rate then by 2022, 65% of the canal will be infilled with sediment and thus an easily increased flood risk.

Several mitigation measures that could be taken to lessen the flood risk associated with the recent sedimentation could be to insert a metallic measuring pole within the cut that would show the height of the sediment. Once the sediment has accumulated to a height of perhaps 90-100 cm then measures could be taken to remove some sediment (perhaps through placing a water pump in the cut that would flush out some sediment).

Bank stabilization techniques upstream could be used to lessen the sediment that travels through the river and into the cut. The best techniques might be plant more vegetation on the banks since the Heathcote does have a lack of vegetation and it is low cost technique. Not only does vegetation stabilize the bank, it also slows the flow of stormwater which allows litter to be trapped and easier removal of some sediment. Bank shaping is another technique that is moderate in cost that removes soil to reduce the slope of very steep banks and thus lessening erosion.

A low to moderate cost technique that would be ecologically beneficial would be to use the Woolston Cut as a sediment trap. Various areas in the upstream section of the Heathcote River may have large amounts of sediment which narrow the banks and affects the biota within the river. If sediment was allowed to accumulate in the cut after traveling downstream, then it could just be routinely removed from the cut since it is a rather insignificant ecological site.

Another measure, that unfortunately would be rather expensive, would be to remove the sediment from the cut using a digger. It was estimated that a 40-ton digger would need 7,203 scoops to remove all the sediment and get the cut back to base level.

Since the Heathcote River is spring-fed, it will take quite some time for the sediment to move out of the Woolston Cut. Storm events would help transport sediment out of the cut, but this would still result in an increased flood risk.

With 46.98% of the cut currently being filled with sediment and subsidence causing lowered elevations of houses, it is very important that measures be taken to reduce the amount of sediment that goes into the cut or to actively remove sediment from the Woolston Cut. Not all floods can be prevented, but we can lessen the flood damage.

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Figure 1. *CCC Survey Data Overlain on Original Woolston Cut Cross Section Schematic*

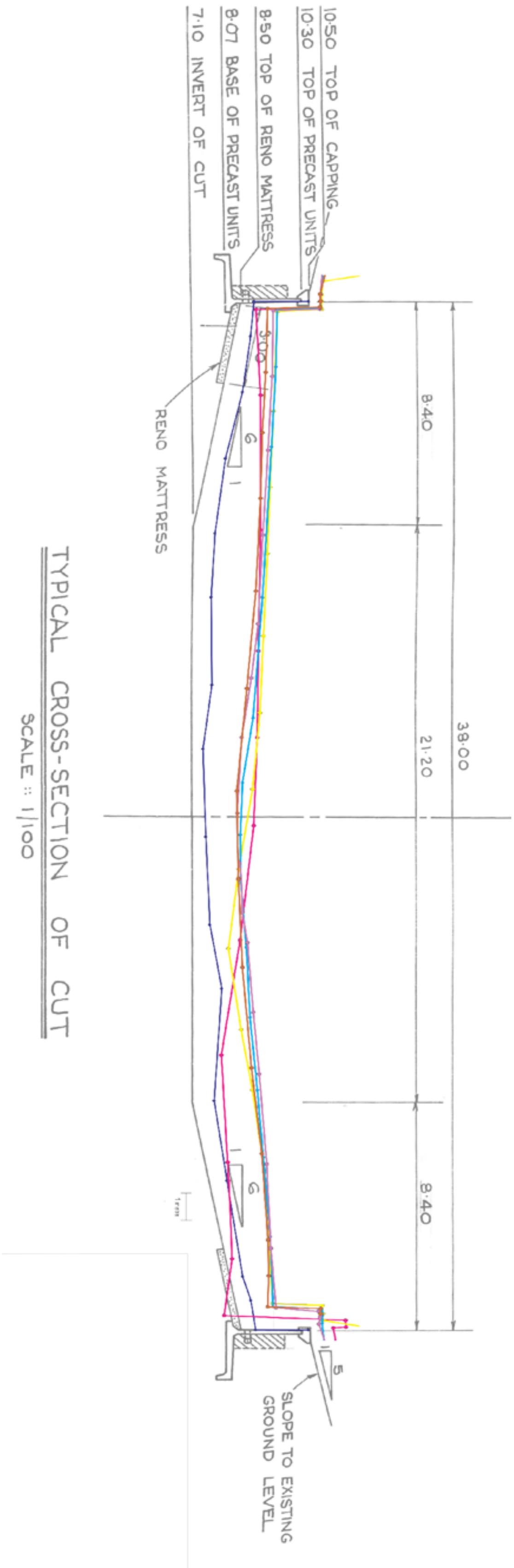

Figure 2. *2011 Cross Sectional Volumes of Sediment*

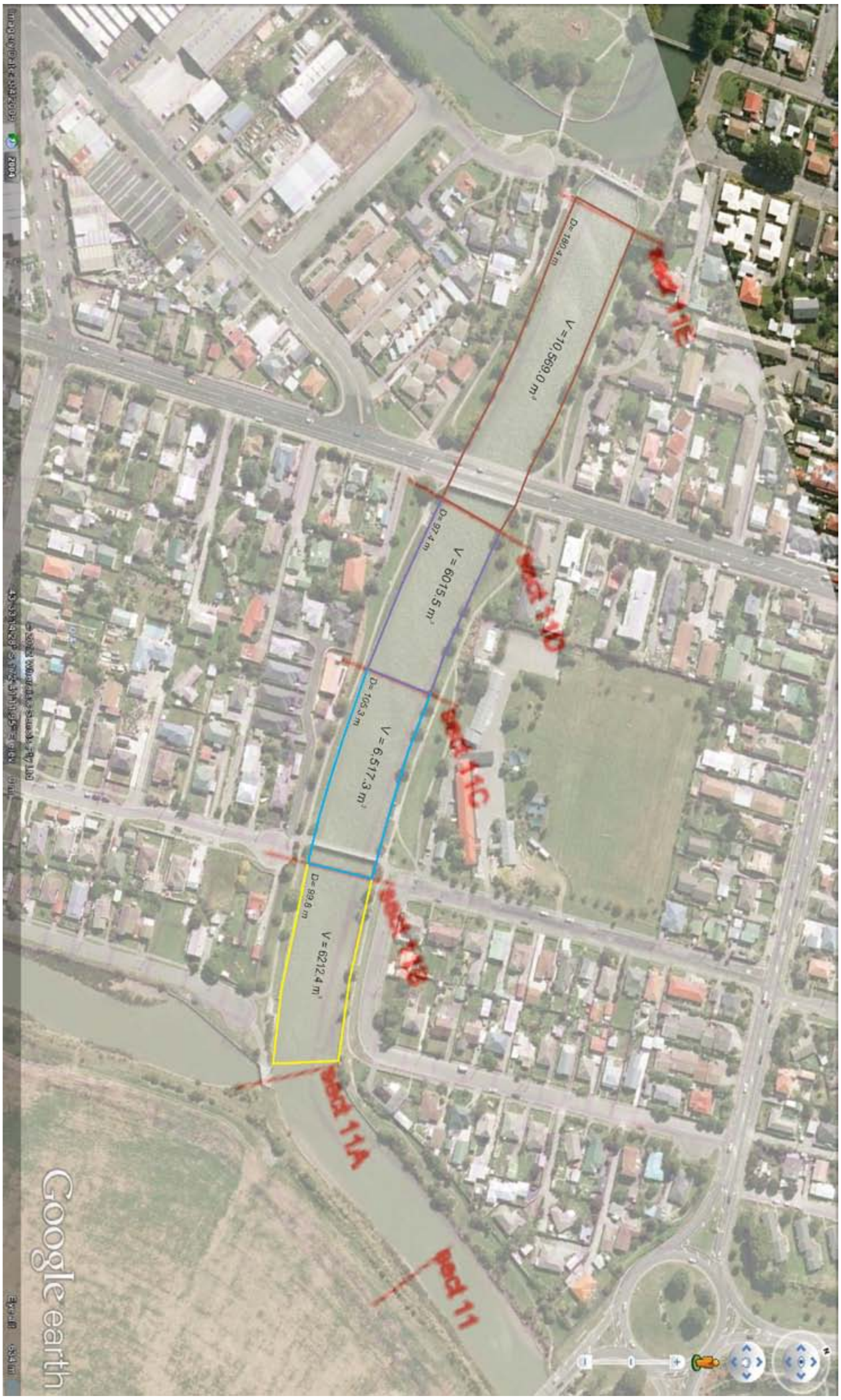

Figure 3. *Stratigraphic Log of Sediment within Test Pit*

Figure 4. *Surveyed Locations at the Woolston Cut*

Figure 5. *Damage in the Cut at Several Locations*

Sediment and excrement within the Woolston Cut.

Lateral Spreading Caused the Cut to Move Inwards and Away from the land.

Uplift of the Cut

Test Pit that was dug 80cm down.